THERMAL CONTRACTION CRACKS IN MARTIAN PERMAFROST: IMPLICATIONS FOR SMALL-SCALE POLYGONAL FEATURES. Michael T. Mellon, NASA Ames Research Center, Moffett Field, CA 94035, mellon@barsoom.arc.nasa.gov.

INTRODUCTION

One of the most ubiquitous geomorphic features in terrestrial permafrost are ice-wedge polygons, formed by repeated seasonal thermal contraction cracking of ice-rich soils. On Mars, similarly small 10 to 100 meter-scale polygons have been observed (not to be confused with the giant multi-kilometer-scale polygons) and have been tentatively attributed to the product of ice-rich soil. These features have the potential to yield valuable information about the distribution of ground ice, the ground ice history, and the climate history. The most direct information to be gained is that the latitudinal distribution of polygons can indicate the latitudinal distribution of ground ice. As a first step in characterizing the formation of polygons on Mars, I have examined the physical processes that produce thermal contraction stress in martian ice-cemented soils with a time-dependent stress-strain model. With this model I determine what conditions are favorable to polygon formation and development and where these conditions exist on Mars.

BACKGROUND FOR THE POLYGONALLY CHALLENGED

Qualitatively, terrestrial thermal contraction polygons form when tensile stress, due to a seasonal decrease in ground surface and subsurface temperatures, exceeds the tensile strength of an ice-rich soil matrix [see Black and Berg, 1963; Lachenbruch, 1962, 1963; Pewe, 1974; Black, 1976]. Prior to fracture the desire to thermally contract is overcome by the strength of the frozen soil, producing tensile stresses. When stresses are high enough to locally exceed the strength, fractures abruptly relieve the stress. Many intersecting fractures over the surface ultimately result in a honeycomb network of vertical cracks, typically penetrating several meters in depth and spaced a few to several tens of meters apart. Once formed, a crack may then fill with surface meltwater at the end of winter, which will freeze at the lower temperatures found in the subsurface, forming what is known as an *ice wedge* [Black, 1976]. In arid regions sand and other surface material may fill the crack forming what is know as a *sand wedge* [Pewe, 1974]. During later seasons the subsurface temperatures warm and thermal expansion acts to compress the crack filling material and typically results in surface relief, or microtopography, marking the cracks and polygon perimeter. While individual cracks may only be a millimeter or two wide in one season, many years of cracking cause wedges to grow to meter-scale widths [eg. Lachenbruch, 1963; Black, 1976]. Typical polygon morphology can consist of a perimeter trough with upturned edges over the ice or sand wedge and a high or low center. In general, morphologies can vary considerably. The requirements for polygon formation are that a porous soil be cemented by ground ice and subjected to adequate cooling; this process is largely independent of soil type [eg. Black, 1976] forming in fine-grained soils and gravels alike.

On Mars small-scale polygonal patterns have been observed in several high resolution Viking Orbiter images [Evans and Rossbacher, 1980; Brook, 1982; Lucchitta, 1983] and Viking Lander 2 images [Mutch et al., 1977], all at latitudes ranging from +17 to +48 degrees. Orbital images show polygonal patterns from 50 to a few hundred meters in size (down to the limit of the resolution [Lucchitta, 1983]), while lander images indicate 10 or more meters in diameter. (Larger, kilometer-scale, polygons have been the subject of much interest and have been shown not to be related to thermal contraction of ice-rich sediments [Pechmann, 1980]. These larger polygons are NOT the subject of this work.) The formation of the observed small-scale polygons has been primarily attributed to thermal contraction cracking of ice-rich permafrost, analogous terrestrial permafrost; other suggested mechanisms include lava cooling and desiccation of wet sediments. The connection between polygonal features and thermal contraction cracks in permafrost in a martian climate has not yet been examined.

Previous attempts to link observed polygons to a thermal contraction process has been primarily based on morphological evidence. Mutch et al [1977] favored thermal contraction for Viking Lander polygons because they resembled antarctic sand-filled polygons, but they did not rule out desiccation of wet sediments. Brook [1982] also favored thermal contraction for Chryse Planitia polygons because of the similar scale to ice-wedge polygons on Earth and cited further support by their proximity to other possibly ice-related features, such as rampart craters. Evans and Rossbacher [1980] offered no definitive explanation for polygons in Lunae Planum, but favored a freeze/thaw cycle as in the formation of terrestrial sorted stone circles. Lucchitta [1983] examined morphology and climate conditions for polygons in Deuteronilius Mensae and concluded that their size and shape were compatible with terrestrial thermal contraction forms. The most rigorous analysis of martian thermal contraction polygon formation was done by Pechmann [1980], applying the theory of Lachenbruch [1962] for terrestrial polygons, to examine the origin of large multi-kilometer-size polygons. He concluded that their large scale precludes an origin in thermally contracting permafrost and comments that thermal cracking "can only occur very near the surface where rapid temperature drops are possible", but he does not extend his work to include the small-scale polygons.

MODEL

While large-scale polygons have received a good deal of attention, presently no rigorous analysis exists to support or refute a thermal-contraction origin of the small-scale polygons on Mars or to benefit from the climate implications of the occurrence or absence of such polygons. As a first step in a more rigorous analysis of the physical processes that control polygon formation, I modeled the martian ice-rich soil as a Maxwell viscoelastic solid. Seasonal changes in temperature cause ice-cemented ground to contract or expand. On short timescales the ground responds elastically and builds stress, while on long timescales the response is viscous, relaxing stress. By combining the relative strains produced by thermal contraction, the elastic response, and viscous relaxation, and noting that prior to fracture the total horizontal strain must remain zero, I calculate the resulting stress.

RESULTS

For the present epoch I found that martian seasonal subsurface temperature variations can produce significant horizontal stress in frozen ground. Tensile stresses build during seasonal cooling, reaching a maximum value prior to mid winter. Tensile stresses can reach values that are easily in excess of the tensile strength of ice and frozen soil over much of the planet's surface. The lowest stresses occur, not surprisingly, in the equatorial region due to the combined effects of the low amplitude seasonal temperature oscillation and of the increased viscous relaxation of stress resulting from the higher temperatures. In the polar regions the response to thermal contraction is almost entirely elastic, so tensile stresses can reach rather high values; the low wintertime polar temperatures greatly increase the viscosity and result in viscous relaxation times much longer than a martian year.

Because tensile stresses exceed tensile strengths, I expect that fractures will form in the ice-rich soils, thus making possible the formation of thermal contraction polygons on Mars. Polygon development can then proceed by repeated cracking in subsequent years. Provided that ice-cemented soils are present, thermal contraction polygons should occur on Mars in the mid and high latitudes and may occur in the equatorial regions under favorable conditions. Crack spacing will depend on the depth of fracture and release of horizontal stress during fracture. As a rule terrestrial crack spacing is observed to be typically about 3 to 10 times the crack depth which is partly controlled by the penetration of the seasonal thermal wave and the distribution of ice. Given these factors I expect polygon diameters to be of order 10 meters (similar to their terrestrial counterparts). A more rigorous analysis of fracture mechanics and the formation of microtopography that can be observed is presently underway.

REFERENCES

Black, R. F. and T. E. Berg, *Proc. Permafrost Int. Conf.*, Nat. Acad. Sci.-Nat. Res. Counc., Pub. 1287, 121-128, 1963.; Black, R. F., *QuaternaryRes.*, *6*, 3-26, 1976.; Brook G. A., *Rep. Planet. Geol. Prog., 1982*, NASA TM 85127, 265-267, 1982.; Evans, N. and L. A. Rossbacher, *Rep. Planet. Geol. Prog., 1980*, NASA TM 82385, 376-378, 1980.; Lachenbruch, A. H., *Geol. Soc. Am. Spec. Paper 70*, 69 p., 1962.; Lachenbruch, A. H., *Proc. Permafrost Int. Conf.*, Nat. Acad. Sci.-Nat. Res. Counc., Pub. 1287, 63-71, 1963.; Lucchitta, B. K, *Permafrost: Fourth Int. Conf. Proc.*, Nat. Acad. Sci. Press, 1983.; Mutch, T. A., R. E. Arvidson, A. B. Binder, E. A. Guinness, and E. C. Morris, *J. Geophys. Res.*, *82*, 4452-4467, 1977.; Pechmann, J. C., *Icarus*, *42*, 185-210, 1980.; Pewe, T. L., in *Polar Deserts and Modern Man*, T. L. Smiley and J. H. Zumberge, eds., Univ. Arizona Press, 1974.